Some comments on injecting additional site terms beyond Vs30 in GMMs

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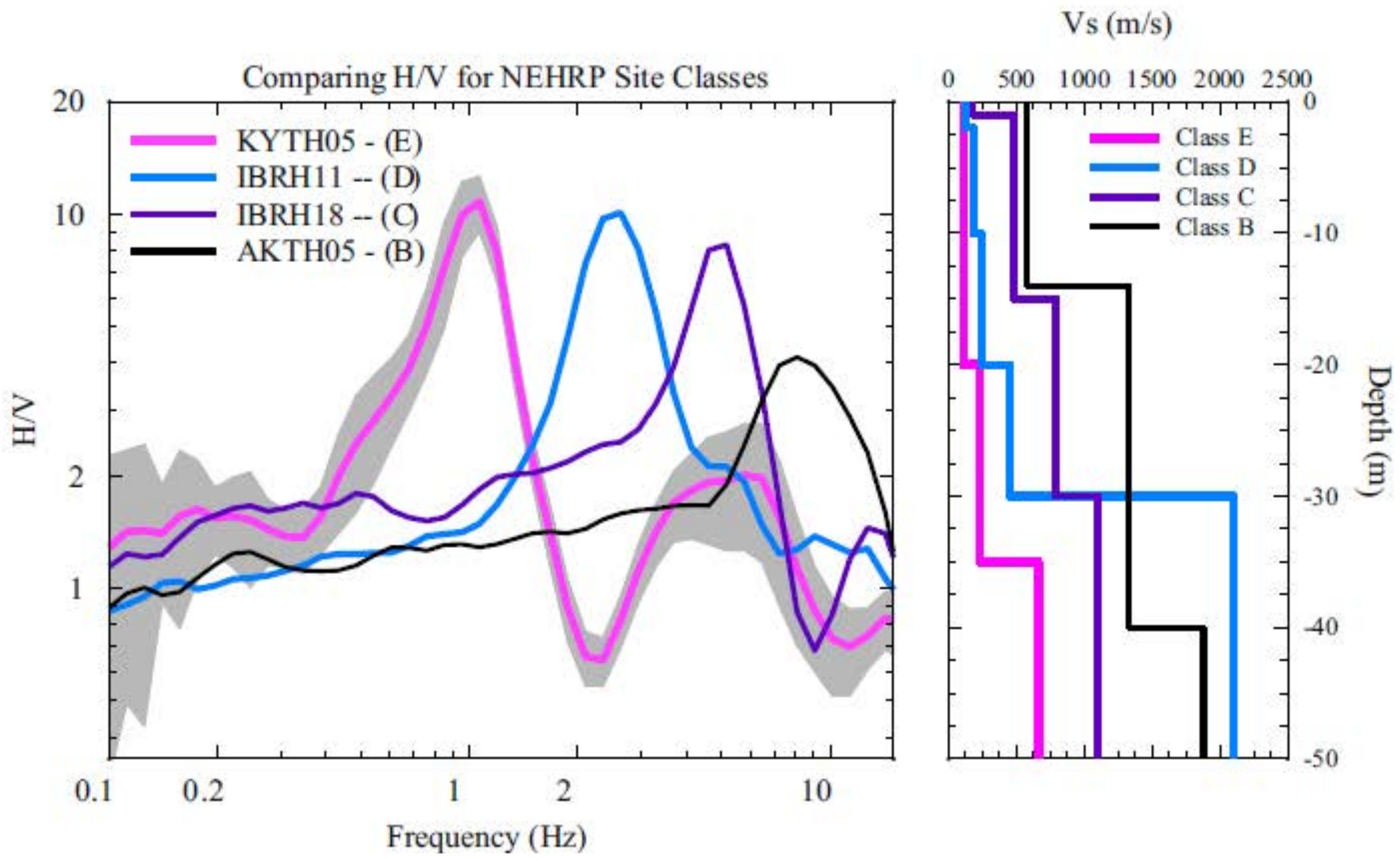
Opinion: We should do this for all GMMs (not just subduction)

Background

- Vs30 is a convenient way to represent site stiffness in GMMs
- there are important period-dependent, region-specific effects not carried by Vs30
- In NGA-W2, these have been considered though a basin depth term – in which amplification is modified according to the depth to bedrock, Z2.5; reflects long-period amplification for deep sites (which CB14 note are different in Japan vs. Calif.).
- In Cascadia, this has been included in some GMMs through considering the difference between typical amplification (for the same Vs30) in Seattle region vs. Japan (e.g. Atkinson and Boore, 2003; Atkinson and Adams, 2013)
- In the east there have been recent proposals to include an analogous term – based on peak frequency, where peak frequency is inversely related to Z2.5 (e.g. Hashash et al., 2016; Kwak and Stewart, 2017; Hassani and Atkinson, 2017); similar in concept but considers shorter periods having significant response at many eastern sites (and also Japan)

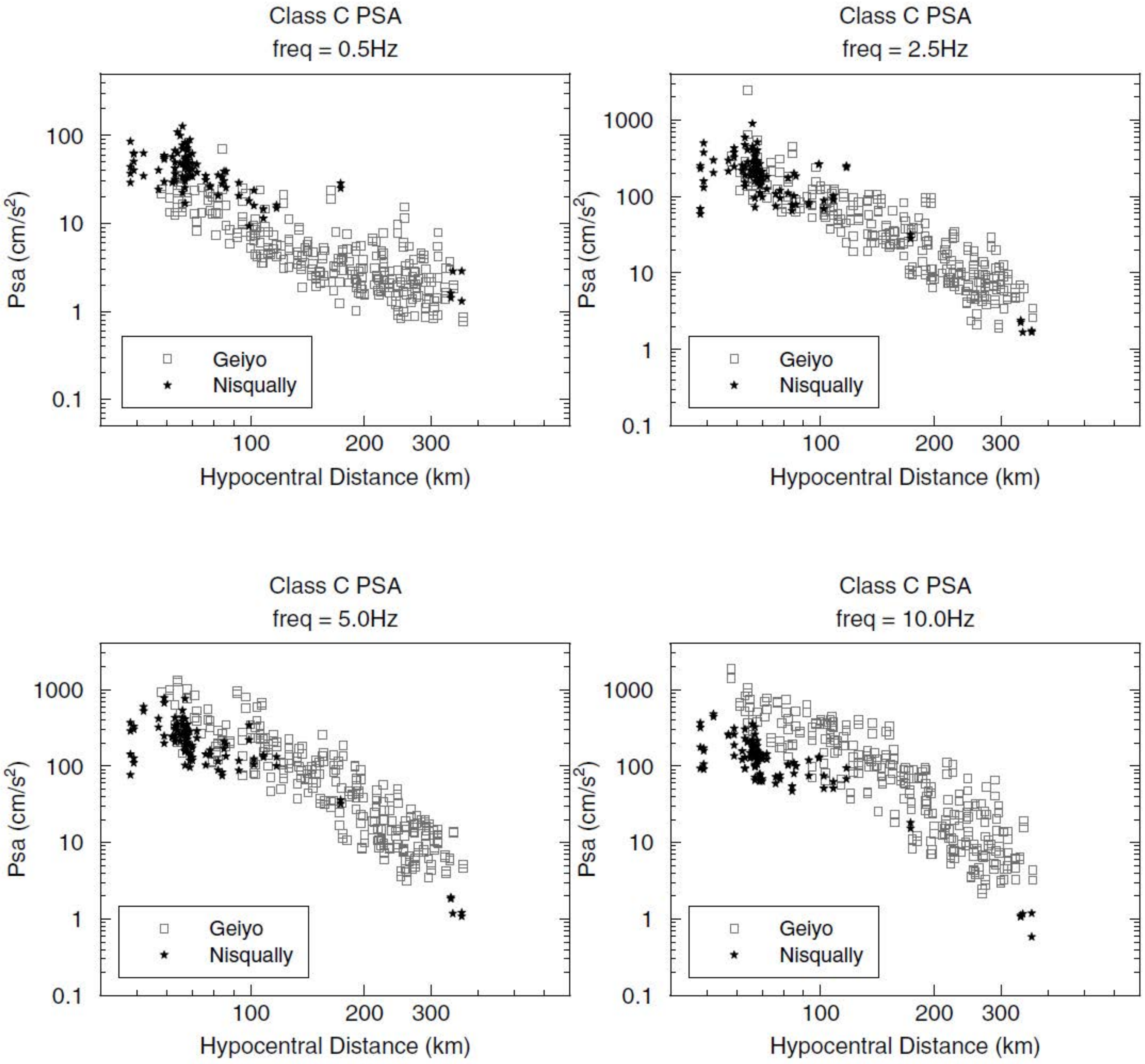
The importance of peak frequency

- Example amplification (from H/V or ratio of surface-to-borehole) for sites in Japan – typically shallow soil over harder layer (Ghofrani and Atkinson, 2013)
- Many sites have a significant impedance contrast in top 30m, leading to peak frequencies in 2 to 10 Hz range
- Lower Vs30 tend to be deeper profiles



How this plays out in Japan vs. Cascadia

- Nisqually vs. Geiyo **M**6.8 in-slab events at h~55 km, recorded on NEHRP C sites (Atkinson and Casey, 2003 BSSA)
- Cascadia/Japan high at low frequencies (factor of 1.5)
- Cascadia/Japan low at high frequencies (factor of 2)



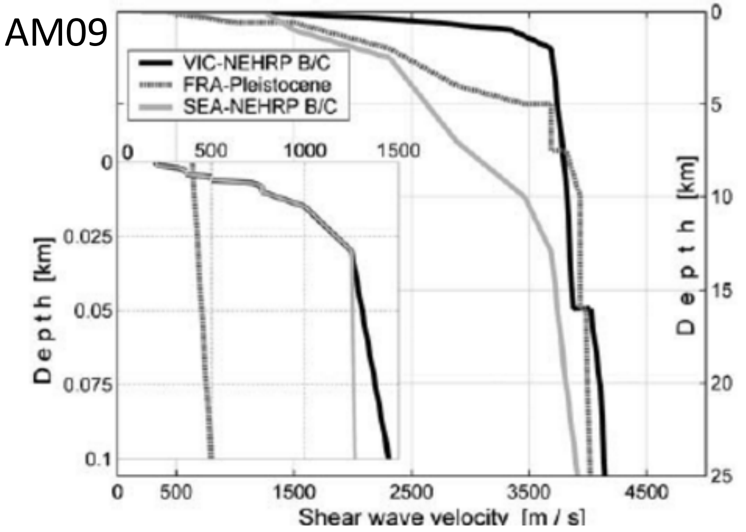
Cascadia Factors: (Cascadia basin sites relative to Japan shallow sites; applied to those GMMs based on Japan data, for NBCC2015)

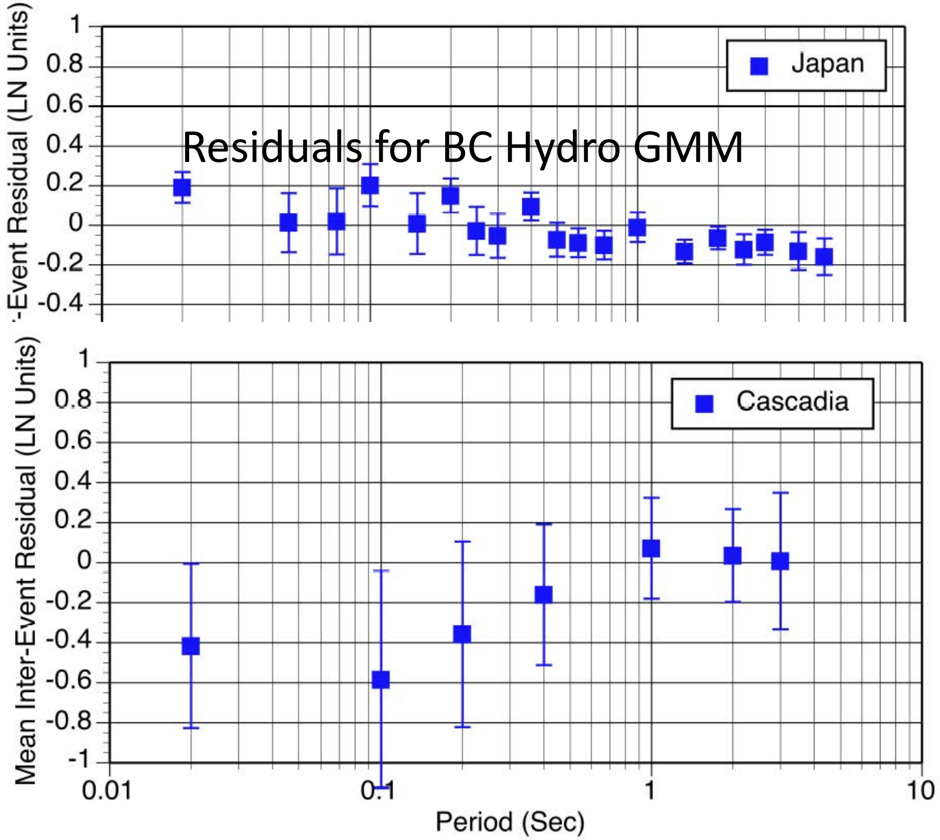
Table:		Cascadia/Japan site factors:	
Freq.(Hz)	Geiyo Vs. Nisqually Atkinson&Casey	AB2003 GMM Atkinson&Boore	Recommended Cascadia Multiplicative Factor (log)
0.1			1 (0.000 log units)
0.2			1.10 (0.04 log units)
0.33		1.23	1.20 (0.079 log units)
0.5	1.47	1.55	1.51 (0.179)
1	1.08	1.00	1.04 (0.017)
2.5	1.16	0.83	1.00 (0.000)
3.33			0.81 (-0.091)
5	0.71	0.50	0.60 (-0.222)
10	0.53	0.35	0.44 (-0.357)
25		0.35	0.44 (-0.357)
PGA		0.45	0.50 (-0.301)
PGV			1.00 (0.000)

Site factors beyond Vs30: in Cascadia GMMs

- Use of add-on factors should depend on the GMM, application
  - E.g. Atkinson and Macias (2009) was a simulation-based GMM for a regional B/C site from Frankel (at right); so an amplification term for basin effects could be added (relative to B/C)
  - Atkinson and Boore (2003) had separate site terms for Cascadia (from Nisqually) vs. Japan that implicitly included the average basin term through use of “Cascadia factors”
  - Zhao (2006) largely based on Japan setting, so deep basin term should be additive (might also need to take out short-period Japan response)
  - BC Hydro used a combination of settings; the residuals (at right) likely reflect regional site response differences (Japan is high at short periods relative to Cascadia; trend switches longer periods)
- So basin terms could/should be added to GMPEs in basin settings in Cascadia for some GMMs (e.g. AM2009)
- For other GMMs (e.g. Zhao, 2006; BCHydro?) it may be needed to account more broadly for period-dependent site response effects (e.g. Cascadia factors)

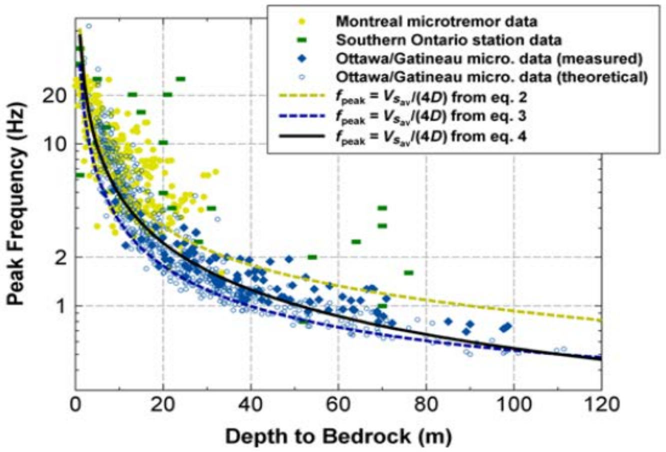
Assumed profile, AM09

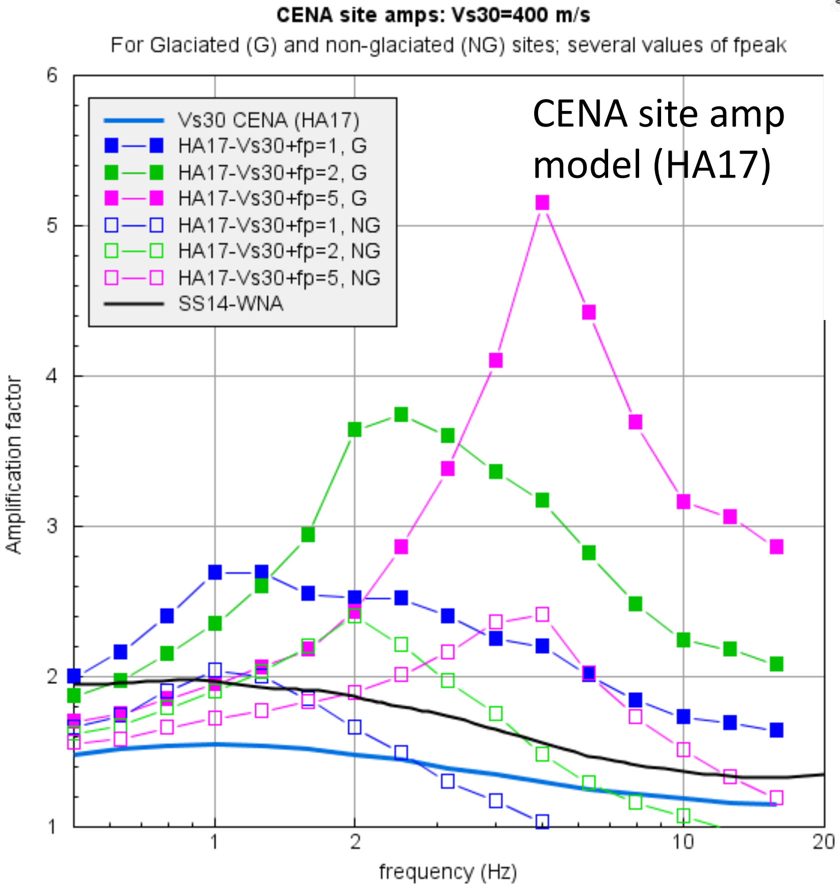




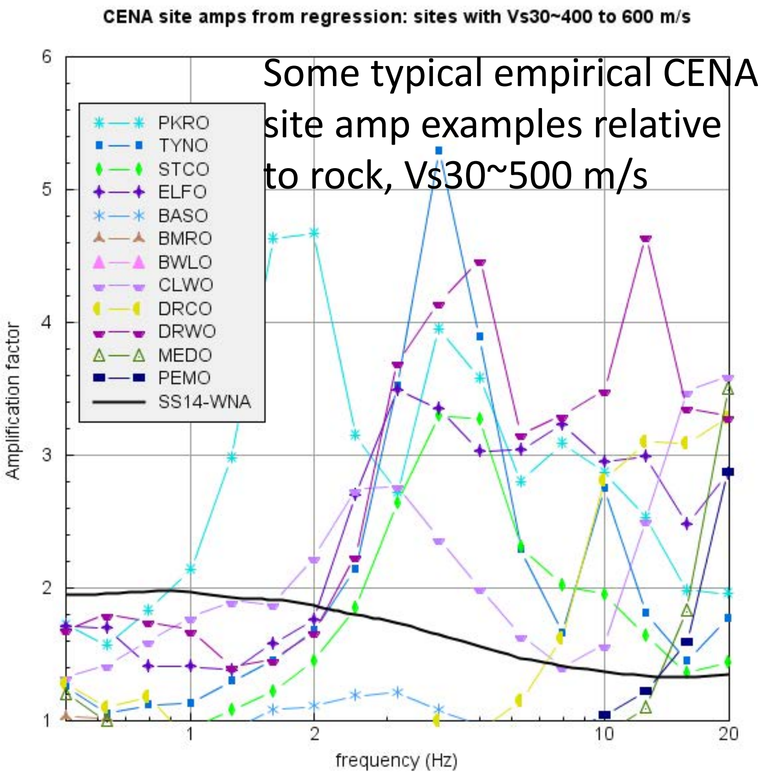
How this plays out the east

- there is an important high-frequency site response not captured by Vs30 scaling
- Peak frequency of response depends on depth to bedrock (right; from Braganza et al., 2016): fp~50/Z
- Far right shows responses for sites from regression of CENA data (NGA-East plus) (Atkinson et al., 2015 BSSA GMM for rock, ~weighted mean NGA-E models)
- Developed model (near right) includes both Vs30 and peak frequency (from Hassani&Atkinson, 2017 BSSA)





CENA site amp model (HA17)

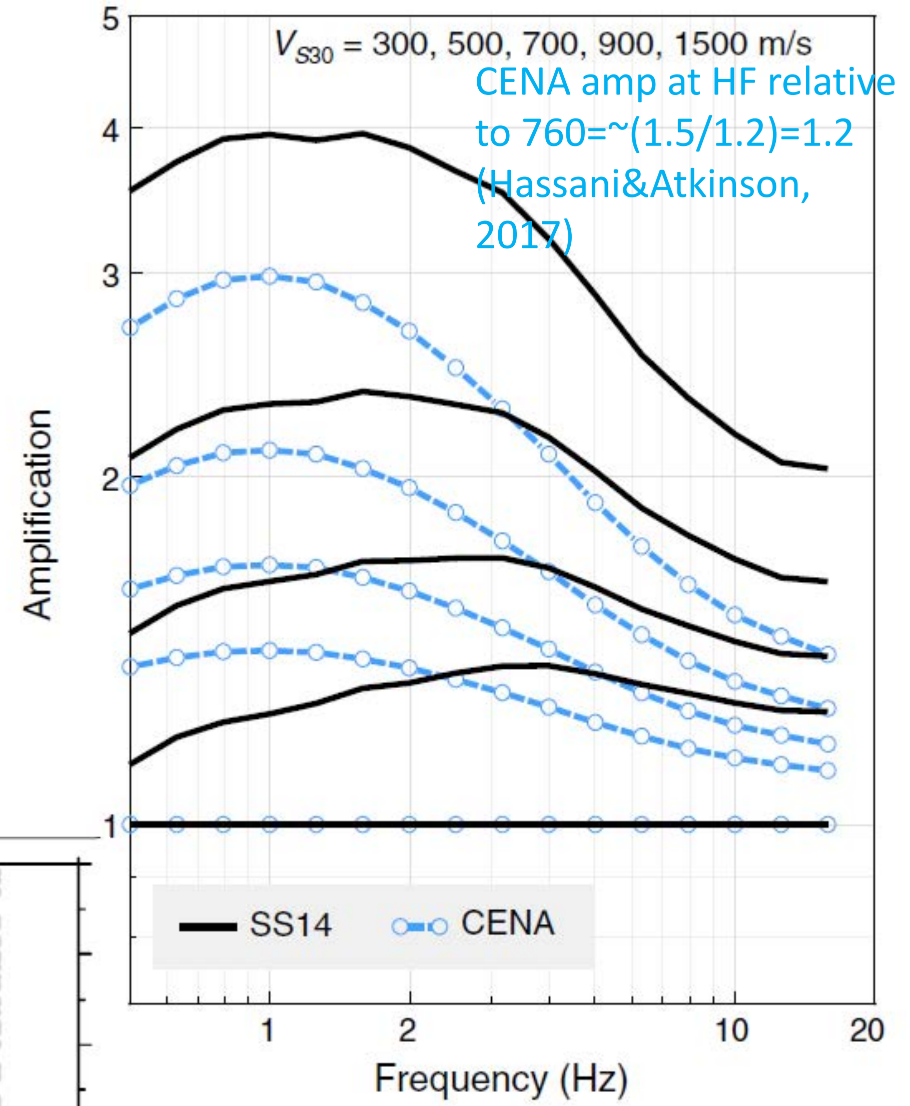


Some typical empirical CENA site amp examples relative to rock, Vs30~500 m/s

If we average amplification over many sites, and consider Vs30 as the sole predictive variable, we get very little average amplification as a function of vs30 (blue line at left, less amplification than Seyhan and Stewart, 2014 WNA model)

CENA Vs30 model

- Site amplification scales more mildly with Vs30 in CENA than it does in WNA (e.g. Seyhan and Stewart, 2014) – especially at higher frequencies
- at right is amplification model based just on Vs30 from Hassani and Atkinson (2017), derived from NGA-East data; suggests lesser site amps in CENA vs WNA (SS14)
- Scaling with Vs30 from HA17 in agreement with Stewart et al., 2017 report, also Hashash et al., 2016 sims

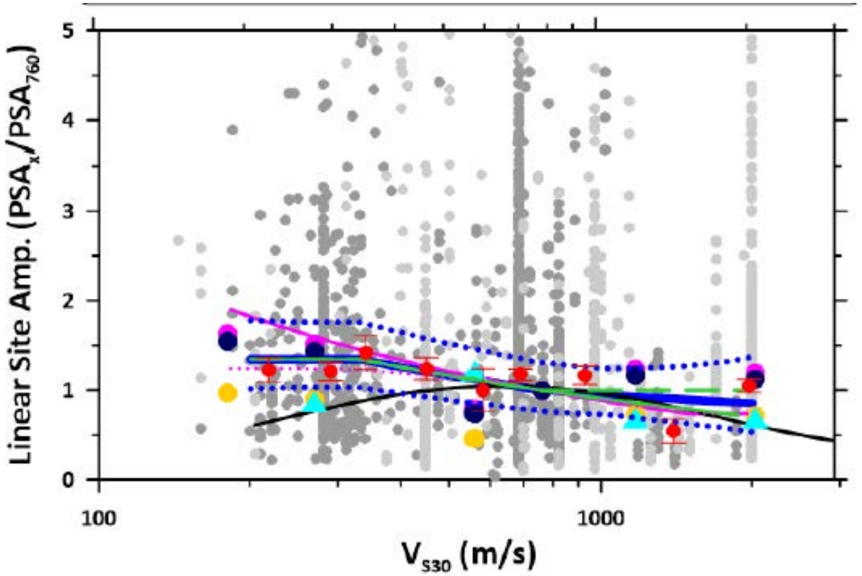


(Stewart rpt for 12Hz at right)

(relative to 760m/s)

(blue is median model;

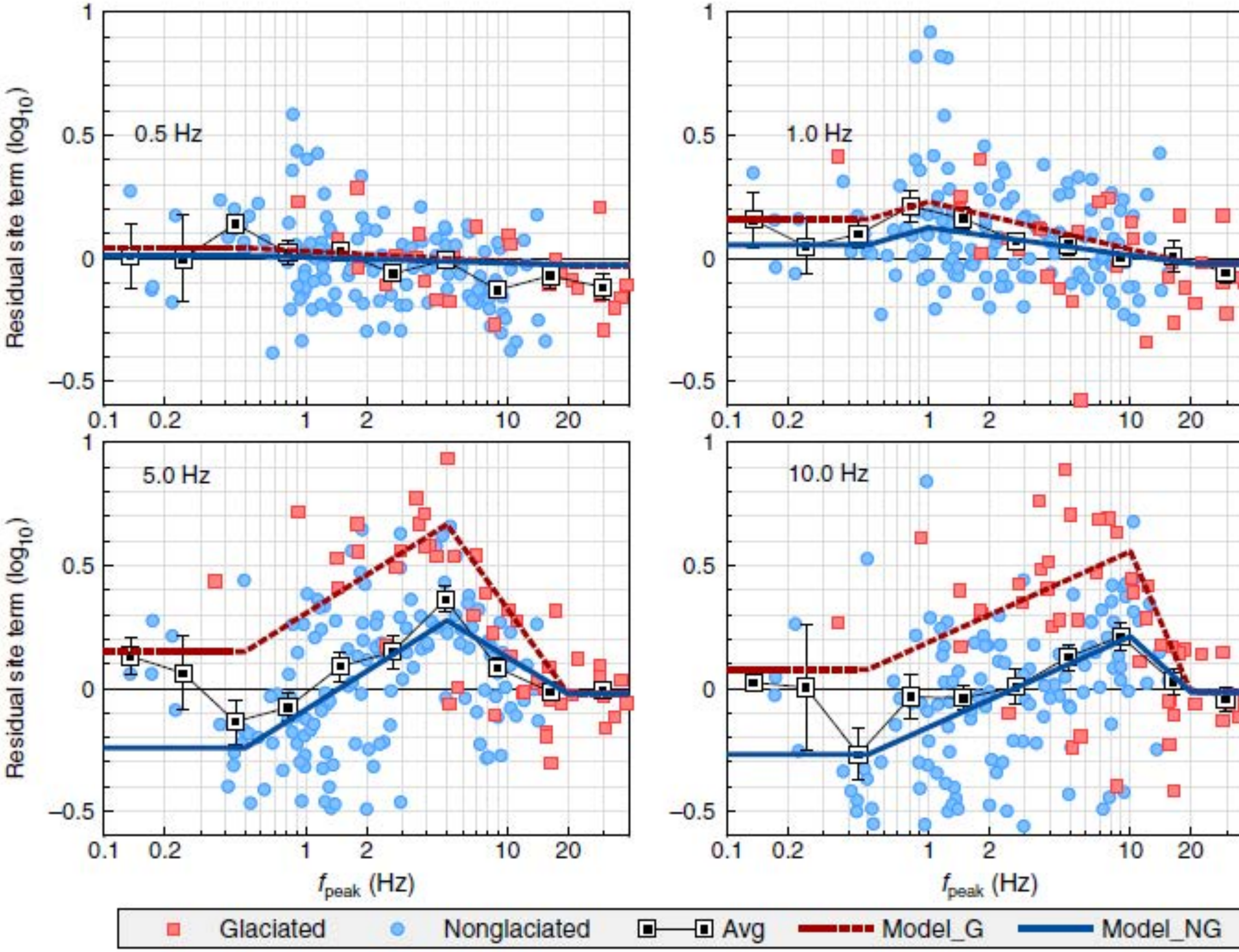
Symbols show alternatives)



....note large scatter of residuals relative to the trend in Vs30

Impact of modeling CENA with Vs30 model only

- After removing the CENA Vs30 effects, there is a structure in the residuals that can be seen if you rearrange to plot residuals vs. peak frequency (this is like a basin term, but at higher freq)
- The Vs30-based model is missing peak response over a significant frequency band at about 60% of sites (especially glaciated) by > factor of two.



Residuals arranged by peak frequency (from H/V) after removing the CENA Vs30 model (from Hassani and Atkinson, 2017)

CENA model should include both Vs30 and peak frequency (or depth to bedrock, Z2.5 or Z1.5)

- Amplifications at right (from Hassani and Atkinson, 2017) are relative to Vs=1500 m/s
- Contrary to model using just Vs30, if we consider the frequency of response, we find CENA site amps are generally larger than the SS14 WNA model over significant frequency ranges (not smaller)
- CENA site amps especially high for glaciated sites
- So we should have a Z1.5 or Z2.5 term (or equivalently fpeak) for CENA
- This accords with results/conclusions of Hashash et al. 2016 report – and also the recommendations of the Stewart rpt

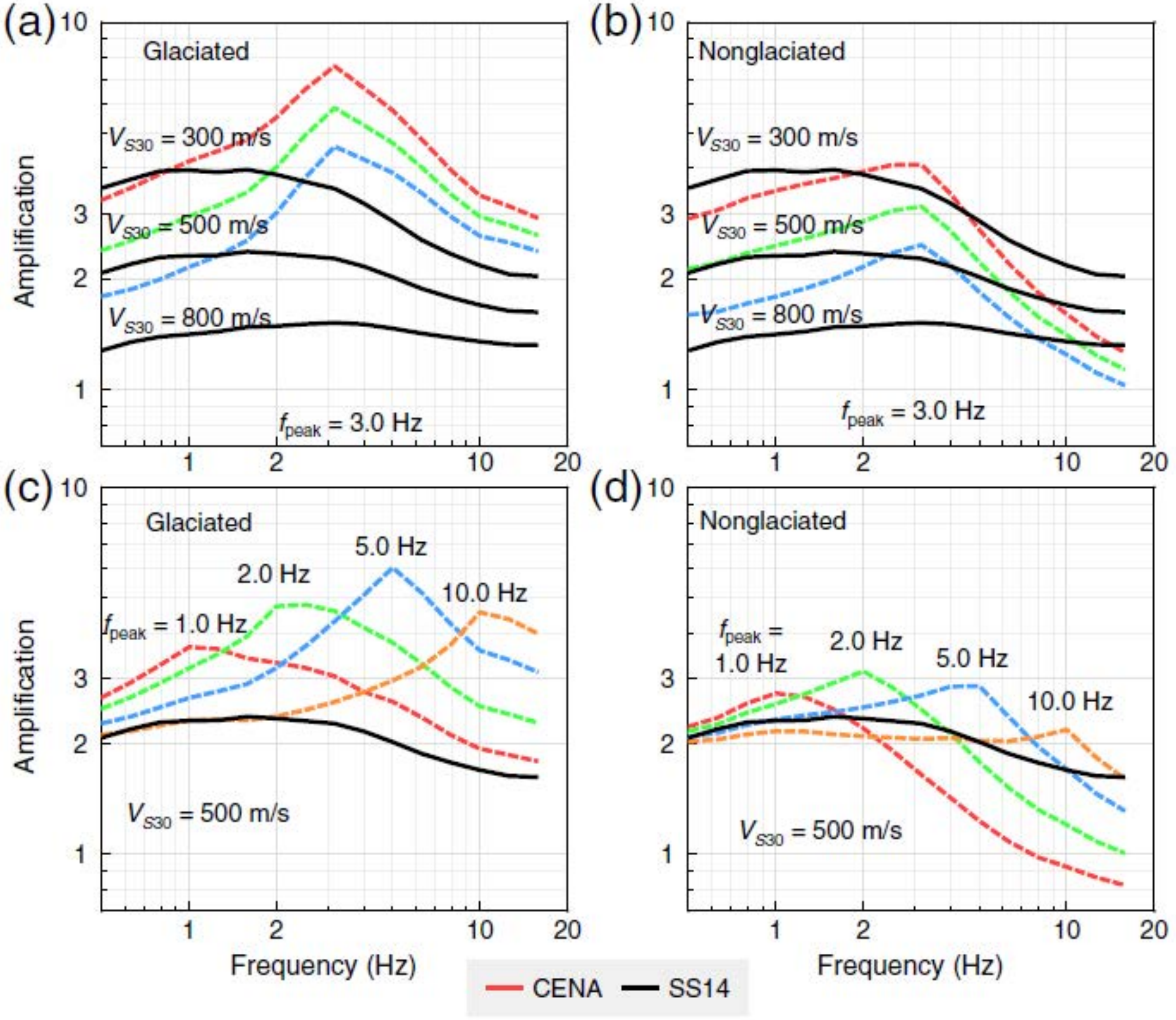
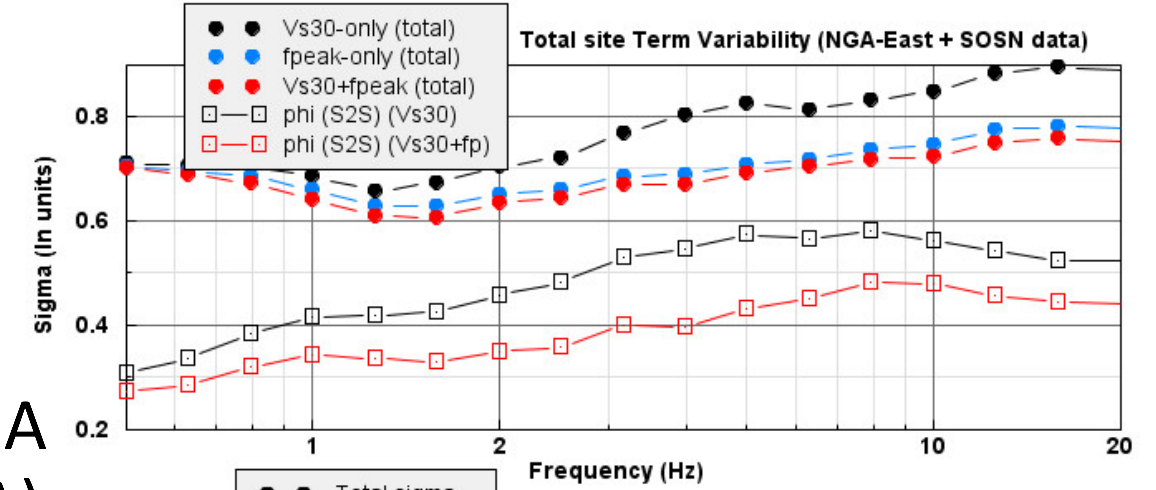
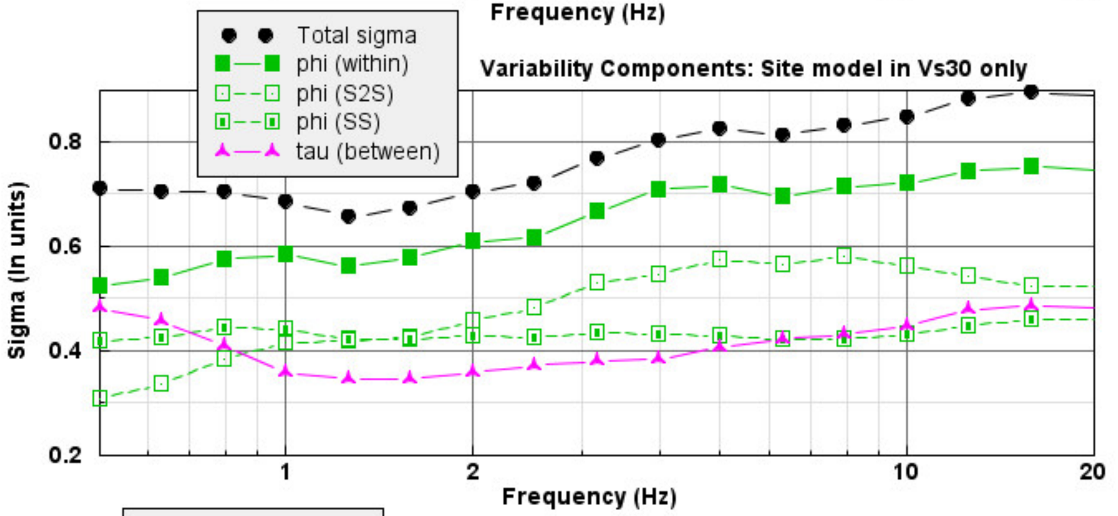


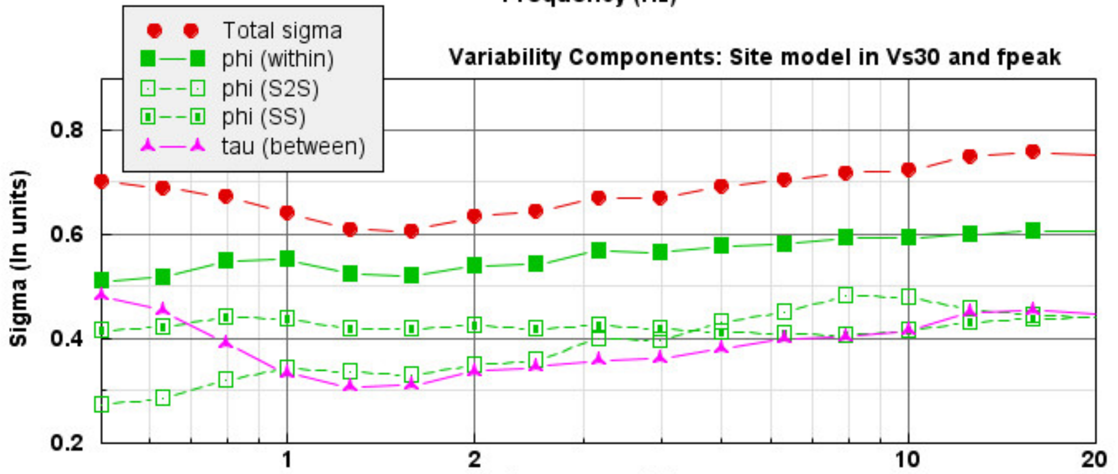
Figure 13. Amplification model for CENA, assuming V_{S30} as the main site-effects parameter and f_{peak} as the secondary parameter, for different V_{S30} and f_{peak} values. (a,b) V_{S30} scaling effects for a site with $f_{peak} = 3$ Hz for three different V_{S30} values (300, 500, and 800 m/s). (c,d) The effects of different f_{peak} values (1, 2, 5, and 10 Hz) for a site with $V_{S30} = 500$ m/s. The SS14 model for western North America is shown for comparison. The color version of this figure is available only in the electronic edition.

Impact of Using Vs30-only in CENA site characterization: Sigma is higher

- Graphs show components of sigma for CENA data from Hassani and Atkinson (2017 BSSA)
  - Total variability and phi (S2S) component (top)
  - Components of variability using Vs30-only (middle)
  - Components of variability using Vs30+fpeak (lower)
- Typical values of phi (total within-event):
  - for NGA-W2 using Vs30-only for site characterization: 0.5 to 0.6 (e.g. BSSA14)
  - for CENA using Vs30-only: 0.6 to 0.7
  - for CENA using Vs30 plus fpeak: 0.5 to 0.6





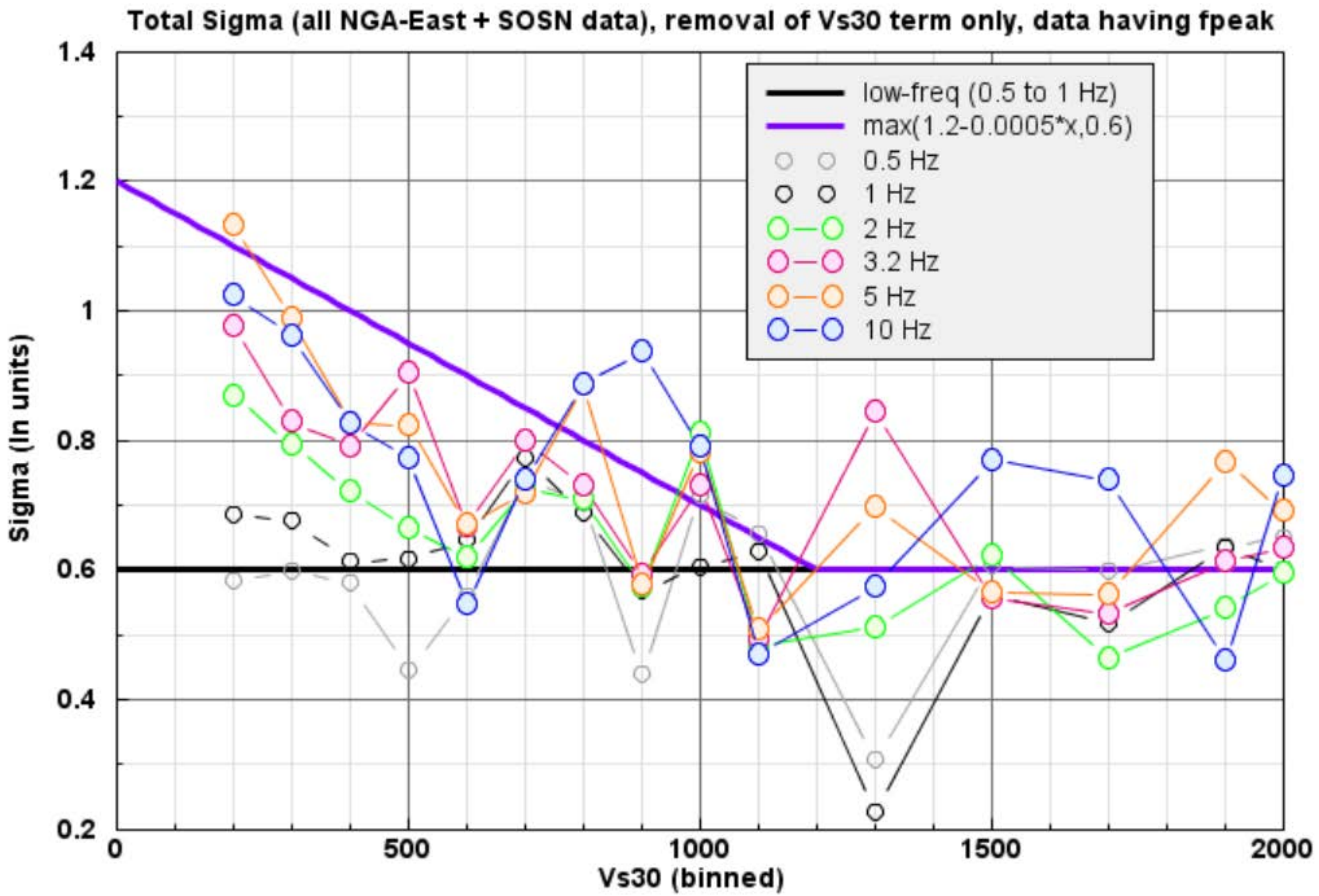


Impact of fpeak on total sigma, versus Vs30 (binned)

(total sigmal from CENA data for sites having fpeak, if only Vs30 effects are removed)

- The extra increment in sigma attributable to fpeak depends on Vs30 and frequency
- This term could be considered to account for neglect of fpeak

(e.g. add the difference between black and purple lines, ~0.1 to 0.5 ln units)



Conclusions

- Additional terms beyond Vs30 are warranted in GMMs in most regions (probably all)
- In some regions (like the east) the additional terms are more important than Vs30
- Cascadia region may have areas where a basin term is important (Puget Sound, Fraser Delta), and areas where a peak-frequency term is important (shallow soils over glaciated rock)
- In using/modifying GMMs it is important to adjust for the appropriate (and dominant) regional site effects

Recommendations

Solution 1- a term in Z2.5 (or equivalently fpeak) could be added to all GMMs

- Add a Z2.5 or fpeak term to GMMs in all regions: this could be a basin term to amplify lower frequencies in some cases (e.g. Cascadia) - or a peak frequency term to amplify higher frequencies in other cases (e.g. CENA; where Z2.5=~50/fpeak)
- If **fpeak is measured (or Z2.5 known)** then a site response term in fpeak can be added (e.g. Hassani and Atkinson empirical or Hashash et al. theoretical)
- If it is **known that there is no fpeak or basin effect** (e.g. site with rock-like profile) then we do not need to add a Z2.5 term.
- If **fpeak is unknown** then an approximate additive term to account for average effects should be applied (e.g. a default amplification term)

Solution 2 (higher sigma)

- If there is no Z2.5 or fpeak term added to CENA GMMs, then a higher sigma is warranted for soil sites in CENA to account for high phiS2S – and a strong caution should be placed in Commentary that some sites have strong peak response exceeding Vs30 model effects by more than a factor of two.

NGA-East PhiS2S